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POSITRON PRODUCTION NEAR A $10^6\ M_\odot$ BLACK HOLE

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ABSTRACT

The annihilation line coming from the direction of the galactic center may be produced by positrons originating from the magnetosphere of a $\sim 10^6\ M_\odot$ black hole.

INTRODUCTION

As discussed by Lingenfelter and Ramaty in these proceedings, one possible origin of the $\sim 10^{43}\ s^{-1}$ positron source tentatively identified with the galactic center sources Sgr A, IRS16 and GCX is a compact region of very high radiation density. Under these conditions, γ-ray photons of energy $E_1 \gtrsim m_e c^2$ produce electron-positron pairs by interacting with photons of energy $E_2 \gtrsim m_e^2 c^4 E_1^{-1}$. The cross section for this process at threshold is $\sim 0.2\sigma_T \sim 10^{-25}\ cm^2$ (Nikishov 1962). In this note, I wish to point out that the necessary efflux of positrons may emerge quite naturally from the magnetosphere of a magnetized $\sim 10^6\ M_\odot$ black hole, as described at this meeting by Thorne and Rees.

Infrared observations of the galactic center suggest the presence of a central ionizing source of power $\sim 10^{40}\ erg\ s^{-1}$ and effective temperature $\sim 30{,}000$ K (Gatley, these proceedings). This could be produced by an accretion disc of effective area $\sim 10^{26}\ cm^2$ surrounding the black hole and being supplied with gas at a rate $\sim 10^{-5}\ M_\odot\ yr^{-1}$ (e.g. Shakura and Sunyaev, 1973). If this were so, the 10 eV photon density near the hole would be $\sim 10^{15}\ cm^{-3}$. Now suppose that the horizon of the hole were threaded with a field of strength $10^4\ B_4$G. If the hole spun with an angular momentum J, an electric field of strength $\sim 3 \times 10^6\ B_4(J/J_{max})\ V\ cm^{-1}$ would be induced in the magnetosphere surrounding the hole. Electrons and positrons could be produced by an electromagnetic cascade process (e.g. Blandford and Znajek 1977, Burns 1980). The basic breakdown mechanism is four stage.

(i) electron (or positron) is accelerated in electrostatic field, induced from the magnetic field by the rotation of the hole, to an energy E_γ

(ii) energetic electron or positron inverse Compton scatters a soft photon of energy $E_{uv} \sim m_e^2 c^4 E_\gamma^{-1}$ to make a gamma ray of energy $\sim E_\gamma$

(iii) gamma ray interacts with a second soft photon to produce an electron and a positron each of energy $\sim .5E_\gamma$

(iv) electron and positron cool rapidly by the synchrotron process from an energy $\sim .5E_\gamma$ to $\sim m_e c^2$.

The cycle then repeats until enough pairs have been produced to short out the electric field component parallel to the magnetic field.

Necessary conditions for this breakdown to occur are that the magnetosphere be optically thick in the soft photons and that the electric field be strong enough to accelerate the electrons and positrons to an energy $\sim E_\gamma$. In our example, the optical depth in the UV photons is ~ 30 and $E_\gamma \sim 10^5$ MeV. The maximum energy to which we could accelerate electrons or positrons can be estimated by balancing electrostatic acceleration with radiation reaction. This gives $E_\gamma \lesssim 3 \times 10^6\ B_4^{\frac{1}{2}}\ (J/J_{max})^{\frac{1}{2}}$ MeV. Therefore both of these conditions are satisfied. The total electromagnetic power extracted from a $\sim 10^6\ M_\odot$ black hole is $\sim 10^{40}\ (J/J_{max})^2\ B_4^2$ erg s^{-1}. It is not clear what fraction of this power emerges from the magnetosphere in the form of relativistic particles. This depends upon the effective resistivity of the plasma within the magnetosphere which can only be guessed. However, suppose that a fraction f of this power goes into pairs of energy $E_\gamma \sim 10^5$ MeV and that $B_4 \sim 1$. These primary particles will be created with large pitch angles and will rapidly cool, radiating a synchrotron power $\sim 10^{40}$ f erg s^{-1} in the form of ~ 1 MeV gamma rays. These gamma rays could produce a far larger flux of secondary positrons than is associated with the primary particles. The ~ 1 MeV gamma ray density in the magnetosphere is $\sim 10^{13}$ f cm^{-3} which implies that a fraction ~ 0.1 f of them will be converted into electron positron pairs. The total positron efflux from the magnetosphere would then be $\sim 10^{45}\ f^2\ s^{-1}$ and so we could account for the observed strength of the annihilation line if $f \sim 0.1$.

A spinning, magnetized hole can therefore produce two outflowing beams of mildly relativistic pairs and MeV γ-rays. Positron annihilation will not occur until this beam has been stopped, which observations mandate to be at a distance $> 3 \times 10^5$ Schwarzschild radii $\sim 10^{17}$ cm. The observed variability imposes an upper bound on this distance $\sim 3 \times 10^{17}$ cm. As described by Dr. Ramaty, this annihilation must occur in a partially ionized and comparatively dense gas cloud. Could this be IRS16, displaced by $\sim 1''$ from the compact radio source? The MeV γ-rays produced by the magnetosphere would mostly be beamed parallel to the field and so the spin axis of the hole should not be directly observable at Earth. The electrons and positrons could possibly supply the compact radio source.

Our ignorance of the actual physical conditions within a hypothetical black hole magnetosphere is even deeper than is the case for pulsar magnetospheres where we have comparatively good diagnostics. The foregoing estimates must therefore be regarded as highly uncertain. However, I hope that I have demonstrated that the galactic center positrons could be produced from the environs of a $\sim 10^6\ M_\odot$ black hole in a manner which is electrodynamically and radiatively self consistent.

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